 KENNELLY

BIBLIOGRAPHY

I. ORIGINAL WORKS. Kennedy translated Franz Reuleaux's *Theoretische Kinematik* as *The Kinematics of Machinery: Outlines of a Theory of Machines* (London, 1876; repr. New York, 1963). Among his writings are "The Use and Equipment of Engineering Laboratories," in *Minutes of Proceedings of the Institution of Civil Engineers*, **88**, pt. 2 (1886–1887), 1–153, including over 70 pp. devoted to discussion of the paper; "Experiments Upon the Transmission of Power by Compressed Air in Paris," in F. E. Idell, ed., *Compressed Air* (New York, 1892), pp. 7–52; and *The Mechanics of Machinery* (London, 1886; 4th ed., 1902).

II. SECONDARY LITERATURE. See *Dictionary of National Biography, 1922–1930*, pp. 464–466. The best biographical sketch is *Minutes of Proceedings of the Institution of Civil Engineers*, **227** (1929), 269–275, which cites a number of minor papers and addresses. A portrait appears as the frontispiece in *Minutes of Proceedings of the Institution of Civil Engineers*, **167** (1907).

EUGENE S. FERGUSON

KENNELLY, ARTHUR EDWIN (*b.* Colaba, near Bombay, India, 17 December 1861; *d.* Boston, Massachusetts, 18 June 1939), *electrical engineering.*

Kennelly was the son of David Joseph Kennelly, an Irish-born employee of the East India Company who later became a barrister and practiced in England and Canada, and Kathrine Heycock Kennelly, English-born daughter of a Bombay cotton-mill owner. She died when Kennelly and his older sister were small children; the father later remarried twice and had ten more children. The boy was educated in Britain and on the Continent but did not attend a university.

His interest in engineering having been aroused by a lecture by Latimer Clark on submarine telegraphy, Kennelly left school at fourteen to become an office boy at the Society of Telegraph Engineers (predecessor of the Institution of Electrical Engineers). At fifteen he became a telegraph operator for the Eastern Telegraph Company, whose employee he remained for ten years, acquiring an engineering education through practice and independent study.

In 1887 Kennelly immigrated to the United States, where he became an assistant to Thomas A. Edison and a consulting engineer; in 1894 he founded his own consulting firm with Edwin J. Houston but continued to be active in his own specialty, submarine cables. In 1902 he was appointed professor of engineering at Harvard University, a post he held until he retired in 1930. Between 1913 and 1924 Kennelly had a second appointment at the Massachusetts Institute of Technology. During the remainder of his career he made important contributions in three areas: the theory and practice of electrical engineering, the study of the ionosphere, and the evolution of electrical units and standards.

Kennelly's principal contribution to electrical engineering arose from an early interest (contemporaneously with C. P. Steinmetz) in the representation of alternating-current quantities by complex variables; his first publication on that subject appeared in 1893. A little later another great contemporary with whom his name was to be linked on several occasions, Oliver Heaviside, proposed the representation of the distribution of current and voltage in a cable by hyperbolic functions; Kennelly extended that notion by the use of complex hyperbolic functions and also introduced polar notation for the complex quantities—that is, using $re^{i\theta}$ instead of $x + iy$, where $r = +\sqrt{x^2 + y^2}$ and $\theta = \text{arc tan}(y/x)$—an innovation of considerable pedagogical and practical value.

Kennelly's best-known contribution is his suggestion, following Marconi's success in bridging the Atlantic by a radiotelegraphic signal in 1901, that radio waves must be reflected from a discontinuity in the ionized upper atmosphere. Soon thereafter the same explanation occurred independently to Heaviside, and the name Kennelly-Heaviside layer was given to the region; it is now known as the ionosphere.

In his third major activity Kennelly's interests again overlapped with Heaviside's: both were interested in the evolution of electrical notation, units, and standards. Kennelly served as president of the American Metric Society, officer of the Metric Association, secretary of the standards committee of the American Institute of Electrical Engineers (AIEE), and secretary and president of the U.S. National Committee of the International Electrotechnical Commission, which he had helped found in 1904. He was instrumental in the adoption of a uniform nomenclature and of the meter-kilogram-second (mks) system as an international standard. Kennelly also was president of the AIEE (1898–1900), the Illuminating Engineering Society (1911), the Institute of Radio Engineers (1916), and the International Radio Scientific Union (honorary, 1935). He received several honorary degrees and many medals, including the AIEE's Edison Medal, and was elected to membership of the U.S. National Academy of Sciences and the Swedish Academy.

In 1903 Kennelly married Julia Grice, a physician. They had a daughter, who died in infancy, and a son.

BIBLIOGRAPHY

Kennelly published more than 350 papers and 28 books (18 as coauthor). A bibliography follows the biography by

Vannevar Bush in *Biographical Memoirs. National Academy of Sciences*, **22** (1943), 83–119. Another biography, by C. L. Dawes, is in *Dictionary of American Biography*, XXII (1958), 357–359. An appreciation by the same author appears in *Science*, **90** (1939), 319–321; and by others in *American Philosophical Society Yearbook* for 1939, pp. 453–457, and in *Transactions of the Illuminating Engineering Society*, **34** (1939), 661. Some of Kennelly's MSS and correspondence are in the Harvard University archives.

CHARLES SÜSSKIND

KEPLER, JOHANNES (*b.* Weil der Stadt, Germany, 27 December 1571; *d.* Regensburg, Germany, 15 November 1630), *astronomy, physics.*

Although Kepler is remembered today chiefly for his three laws of planetary motion, these were but three elements in his much broader search for cosmic harmonies and a celestial physics. With the exception of Rheticus, Kepler became the first enthusiastic Copernican after Copernicus himself; he found an astronomy whose clumsy geocentric or heliostatic planetary mechanisms typically erred by several degrees and he left it with a unified and physically motivated heliocentric system nearly 100 times more accurate.

When Kepler was twenty-five and much occupied with astrology, he compared the members of his family with their horoscopes.[1] His grandfather Sebald, mayor of Weil in 1571, when Kepler was born, was "quick-tempered and obstinate." His grandmother was "clever, deceitful, blazing with hatred, the queen of busybodies." His father, Heinrich, was described as "criminally inclined, quarrelsome, liable to a bad end" and destined for a "marriage fraught with strife." When Kepler was three years old, his father joined a group of mercenary soldiers to fight the Protestant uprising in Holland, thereby disgracing his family. Soon after his return in 1576, he again joined the Belgian military service for a few years; and in 1588 he abandoned his family forever.

Although Kepler describes his mother, the former Katharina Guldenmann, as "thin, garrulous, and bad-tempered," he adds that "treated shabbily, she could not overcome the inhumanity of her husband." Katharina showed her impressionable son the great comet of 1577. Later, Kepler spent many months between 1617 and 1620 preparing a legal defense when his aged but meddlesome mother was accused of and tried for witchcraft.

Kepler first attended the German Schreibschule in Leonberg, where his family had moved in 1576; shortly after, he transferred to the Latin school, there laying the foundation for the complex Latin style displayed in his later writings. In 1584 he entered the Adelberg monastery school; and two years later enrolled at Maulbronn, one of the preparatory schools for the University of Tübingen. In October 1587 Kepler formally matriculated at Tübingen; but because no room was available at the Stift, the seminary where, as a scholarship student supported by the duke of Württemberg, he was expected to lodge, he continued at Maulbronn for another two years. On 25 September 1588 he passed the baccalaureate examination at Tübingen, although he did not actually take up residence there until the following year.

At Tübingen, Kepler's thought was profoundly influenced by Michael Maestlin, the astronomy professor. Maestlin knew Copernican astronomy well; the 1543 *De revolutionibus* he owned is probably the most thoroughly annotated copy extant; he edited the 1571 edition of the *Prutenicae tabulae*, and he used them to compute his own *Ephemerides*. Although Maestlin was at best a very cautious Copernican, he planted the seed that with Kepler later blossomed into a full Copernicanism. The ground was fertile. Kepler's quarterly grades at the university, still preserved, show him as a "straight A" student; and when he applied for a scholarship renewal at Tübingen, the senate noted that he had "such a superior and magnificent mind that something special may be expected of him." Nevertheless, Kepler himself wrote concerning the science and mathematics of his university curriculum that "these were the prescribed studies, and nothing indicated to me a particular bent for astronomy."[2]

On 11 August 1591 Kepler received his master's degree from Tübingen and thereupon entered the theological course. Halfway through his third and last year, however, an event occurred that completely altered the direction of his life. Georgius Stadius, teacher of mathematics at the Lutheran school in Graz, died; and the local authorities asked Tübingen for a replacement. Kepler was chosen; and although he protested abandoning his intention to become a clergyman, he set out on the career destined to immortalize his name.

Graz and the Mysterium Cosmographicum. On 11 April 1594, the twenty-two-year-old Kepler arrived in southern Austria to take up his duties as teacher and as provincial mathematician. In the first year he had few pupils in mathematical astronomy and in the second year none, so he was asked to teach Vergil and rhetoric as well as arithmetic. But the young Kepler made his mark in another way; soon after coming to Graz, he issued a calendar and prognostication for 1595, which contained predictions of bitter cold, peasant uprisings, and invasions by the